CERES/Libera Joint Science Team Meeting –

An assessment of climate feedbacks in observations and climate models using different energy balance frameworks

Li-Wei Chao, Andrew Dessler

Department of Atmospheric Sciences, Texas A&M University

Energy Balance Framework

$$\Delta R = \Delta F + \lambda \Delta T_S$$

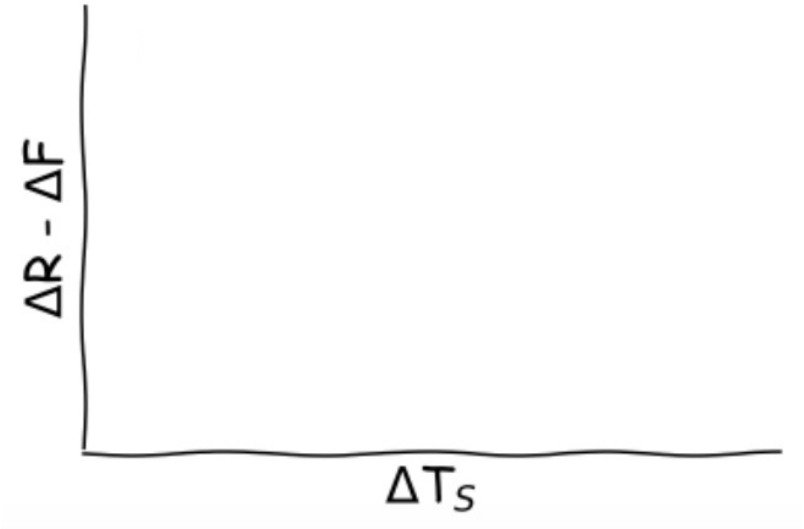
Net TOA flux Forcing Response

Warming,
emit more radiation ↑
Complex processes
→ approximated by $\lambda \Delta T_S$

Energy Balance Framework

$$\Delta R = \Delta F + \lambda \Delta T_S$$

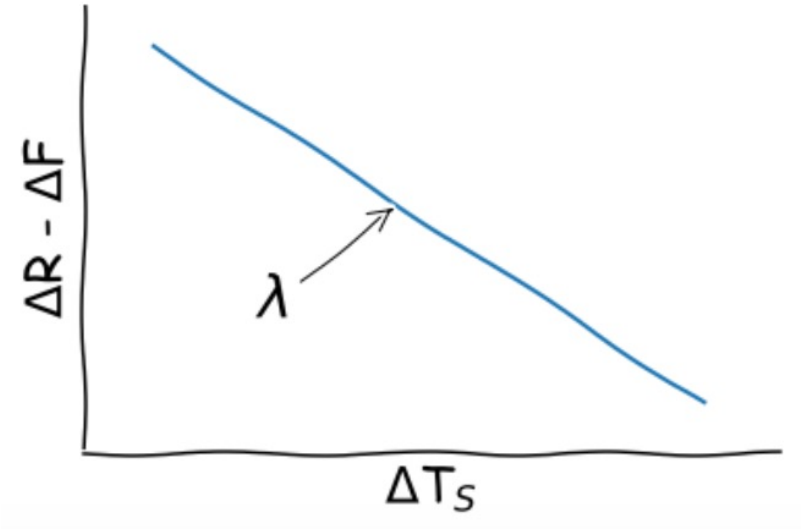
Net TOA flux Forcing Response



Energy Balance Framework

$$\Delta R = \Delta F + \lambda \Delta T_S$$

Net TOA flux Forcing Response



ΔR: CERES EBAF ed4.1
ΔF: IPCC AR5 forcing
ΔT_S: ERA5 reanalysis

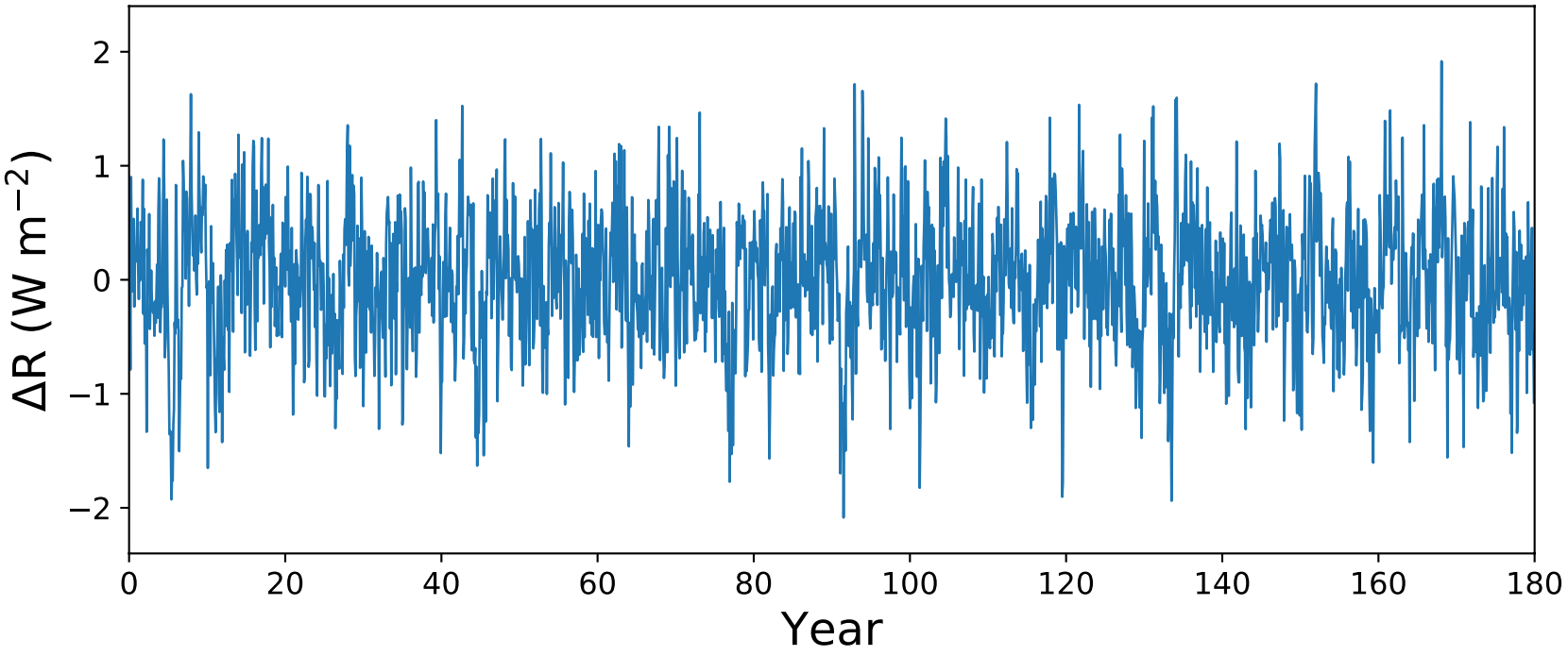
Time:
2000/03 – 2017/10

Compare CERES observations and CMIP6

to build confidence in the estimations from climate models

26 CMIP6 piControl runs

For each model (~500 years):



Compare CERES observations and CMIP6

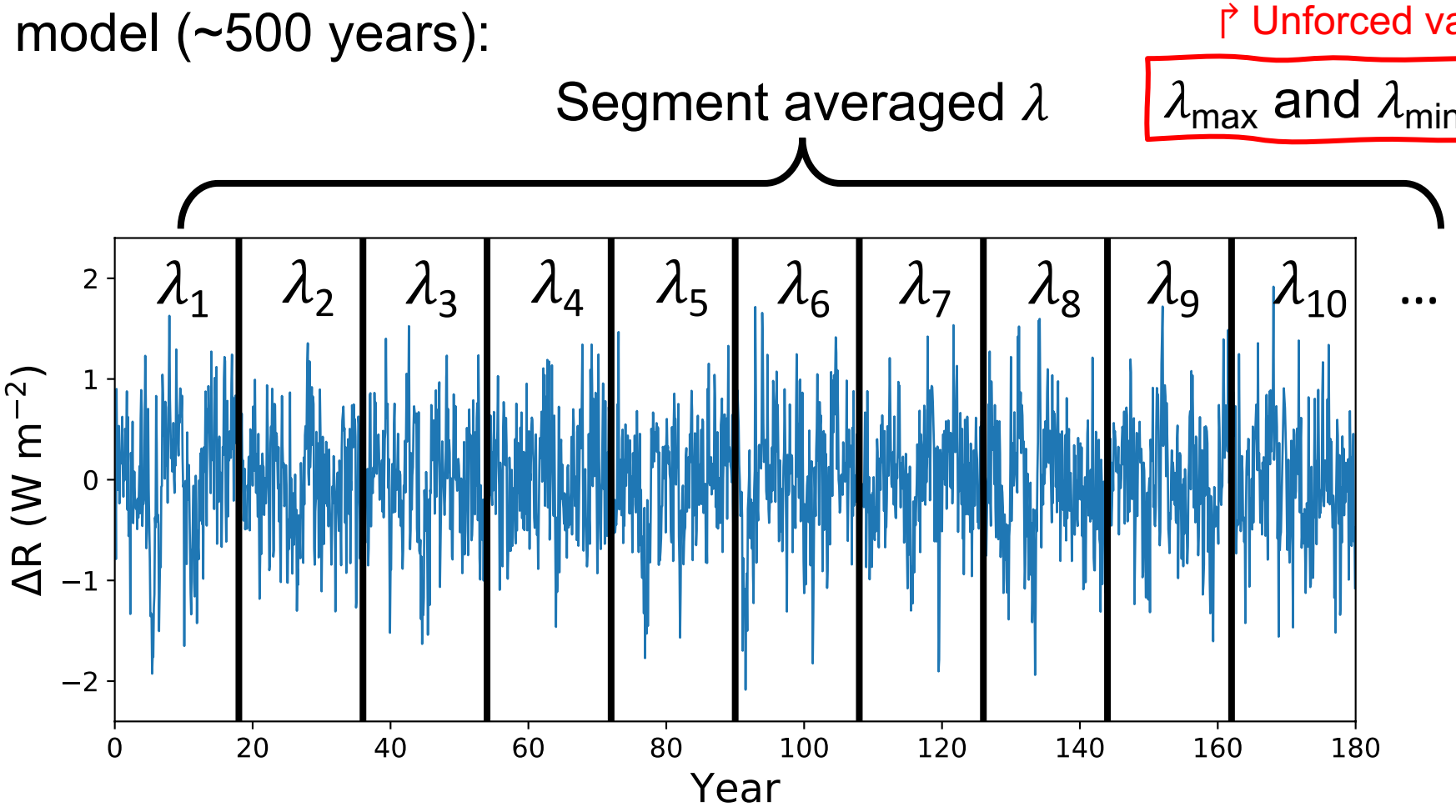
to build confidence in the estimations from climate models

26 CMIP6 piControl runs

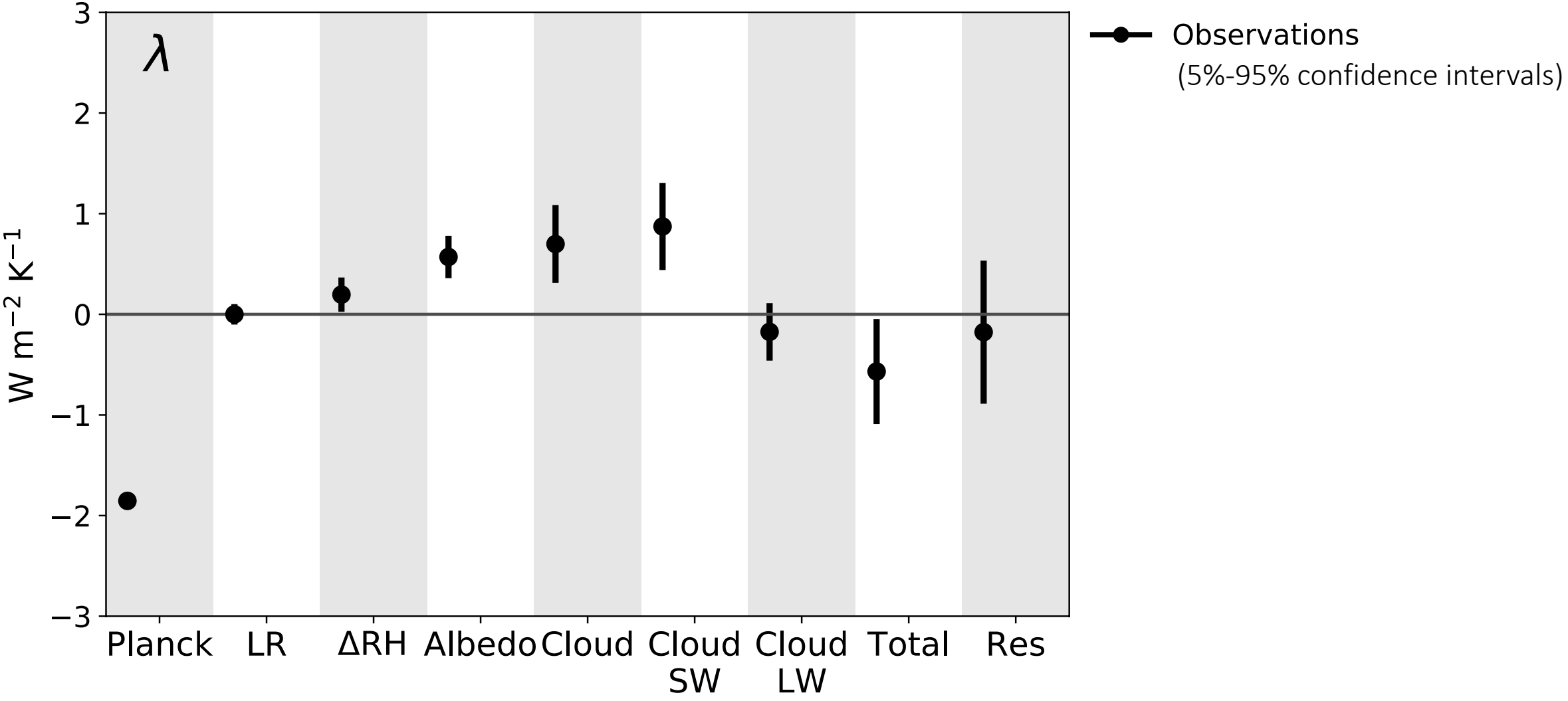
For each model (~500 years):

↱ Unforced variability

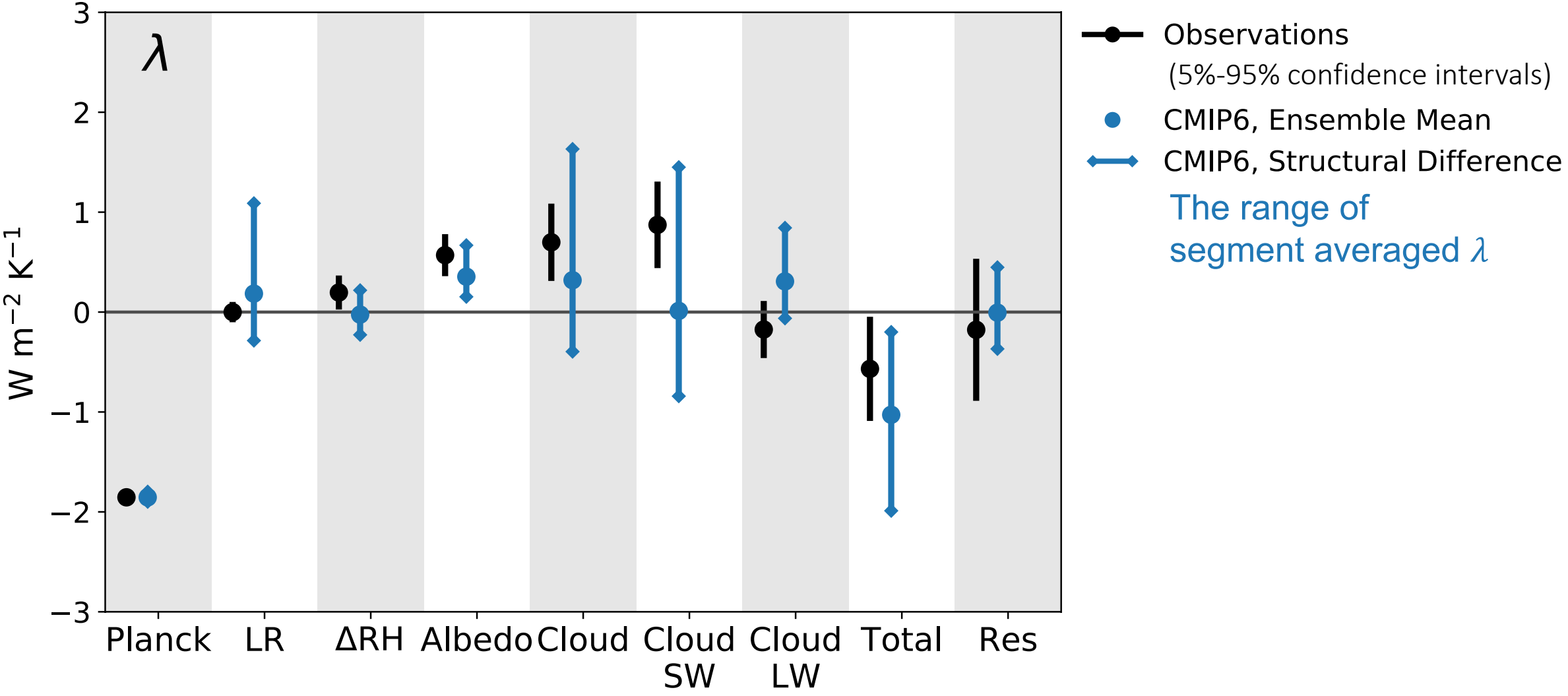
λ_{max} and λ_{min}



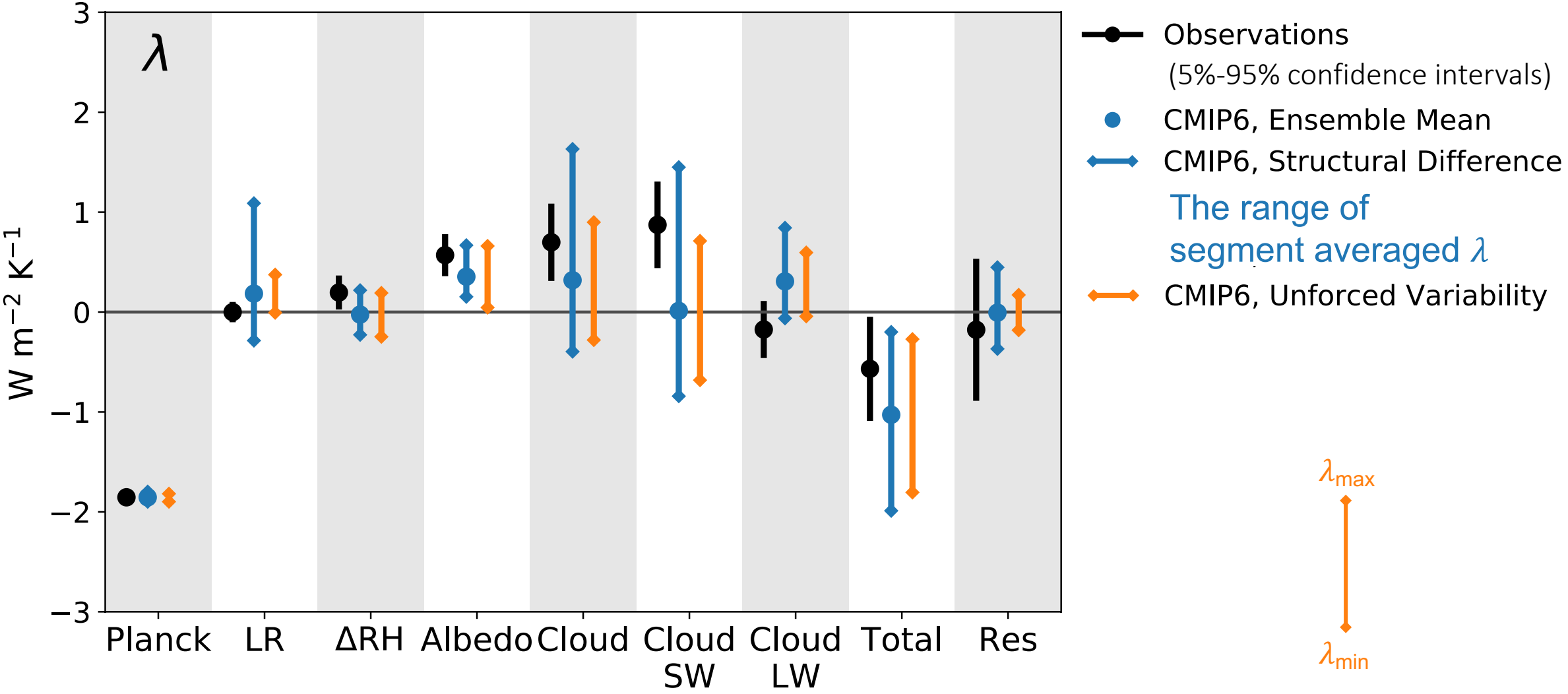
$$\lambda = \lambda_{\text{Planck}} + \lambda_{\text{lapse rate}} + \lambda_{\Delta\text{RH}} + \lambda_{\text{Albedo}} + \lambda_{\text{Cloud}}$$



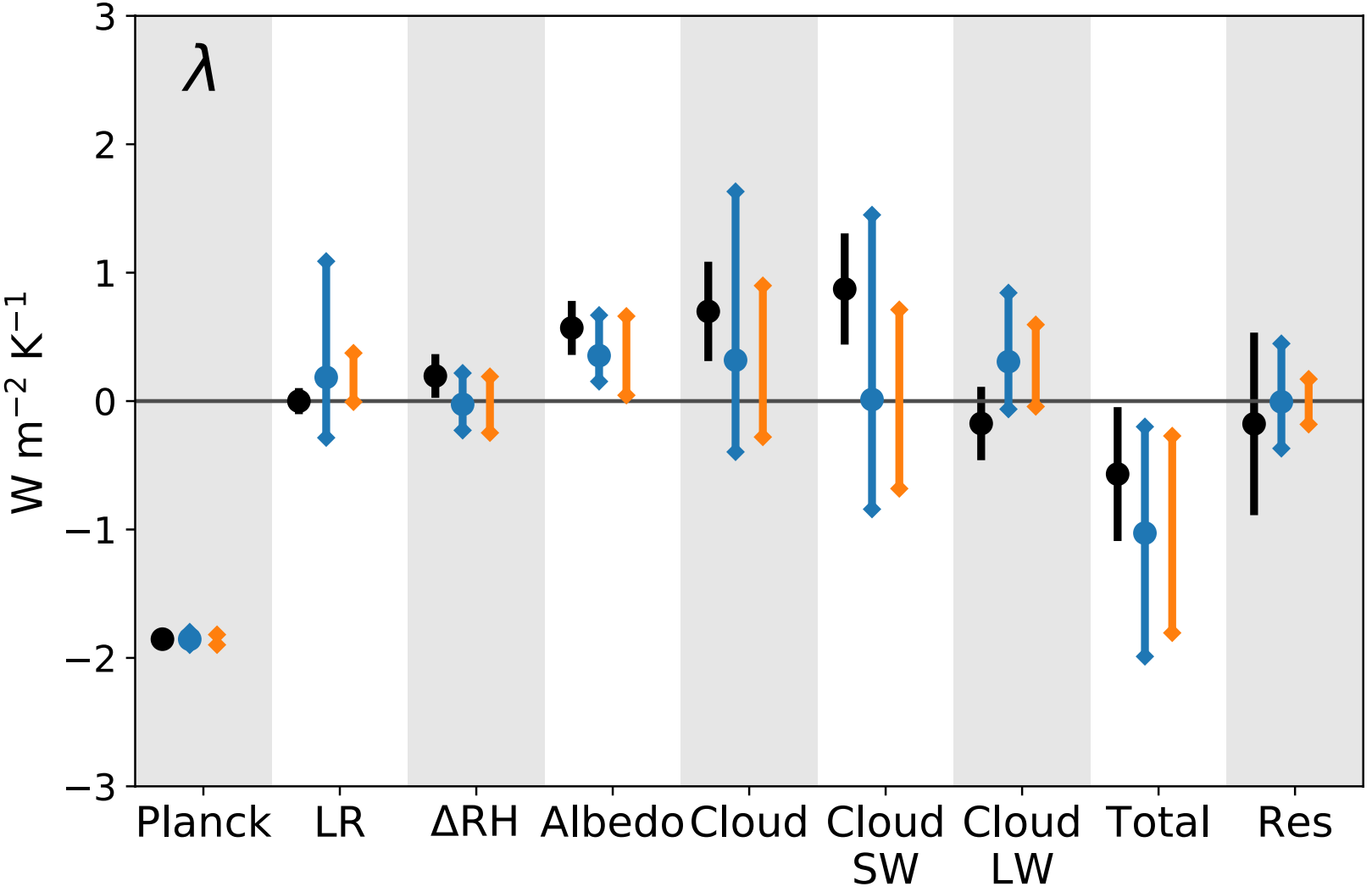
$$\lambda = \lambda_{\text{Planck}} + \lambda_{\text{lapse rate}} + \lambda_{\Delta\text{RH}} + \lambda_{\text{Albedo}} + \lambda_{\text{Cloud}}$$



$$\lambda = \lambda_{\text{Planck}} + \lambda_{\text{lapse rate}} + \lambda_{\Delta\text{RH}} + \lambda_{\text{Albedo}} + \lambda_{\text{Cloud}}$$



$$\lambda = \lambda_{\text{Planck}} + \lambda_{\text{lapse rate}} + \lambda_{\Delta\text{RH}} + \lambda_{\text{Albedo}} + \lambda_{\text{Cloud}}$$



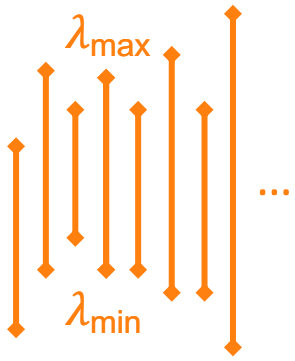
Observations
(5%-95% confidence intervals)

CMIP6, Ensemble Mean

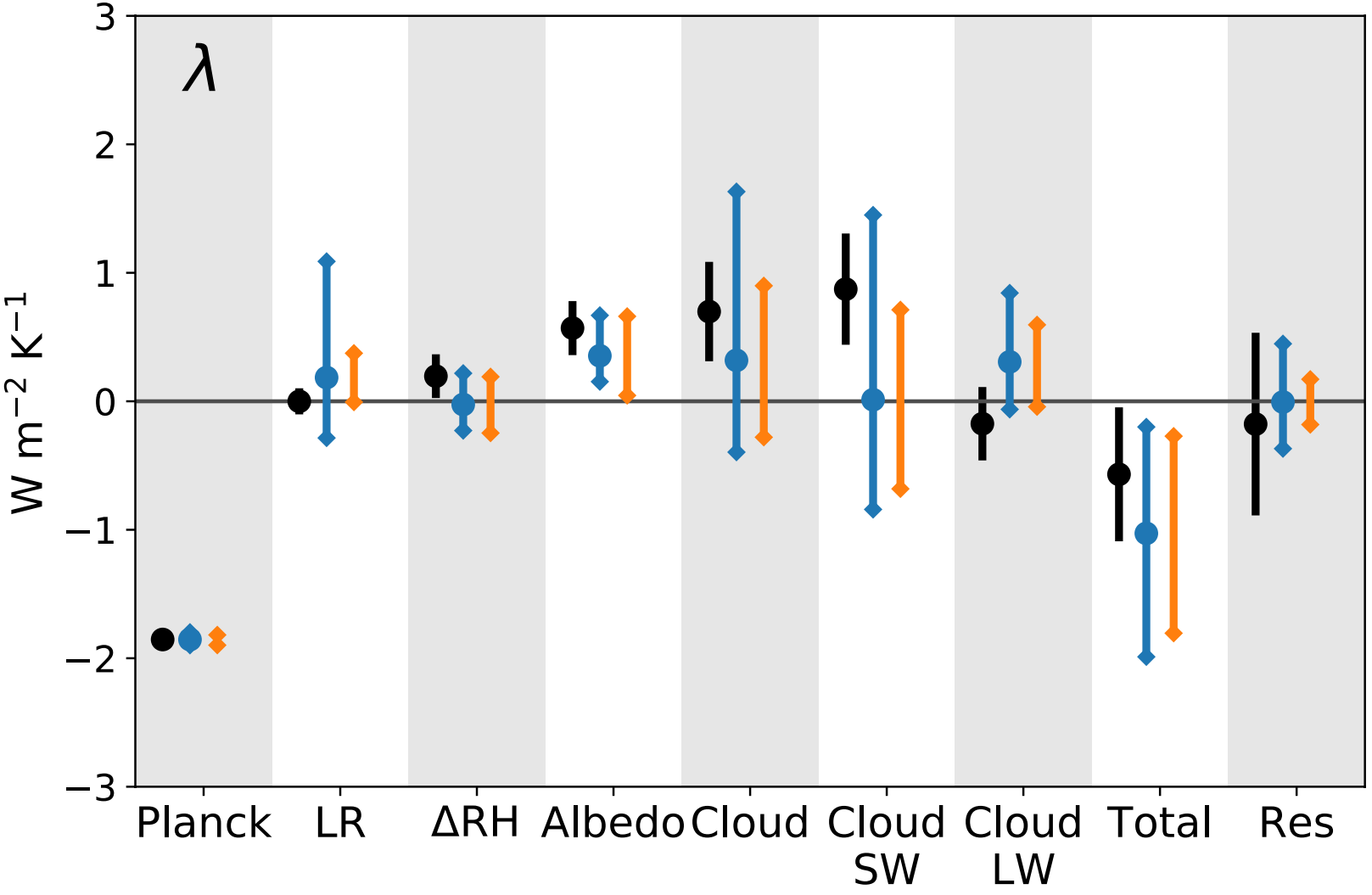
CMIP6, Structural Difference

The range of segment averaged λ

CMIP6, Unforced Variability



$$\lambda = \lambda_{\text{Planck}} + \lambda_{\text{lapse rate}} + \lambda_{\Delta\text{RH}} + \lambda_{\text{Albedo}} + \lambda_{\text{Cloud}}$$



Observations
(5%-95% confidence intervals)

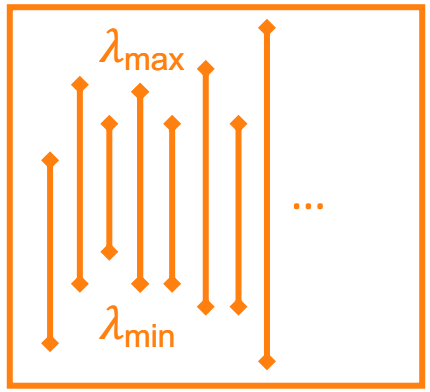
CMIP6, Ensemble Mean

CMIP6, Structural Difference

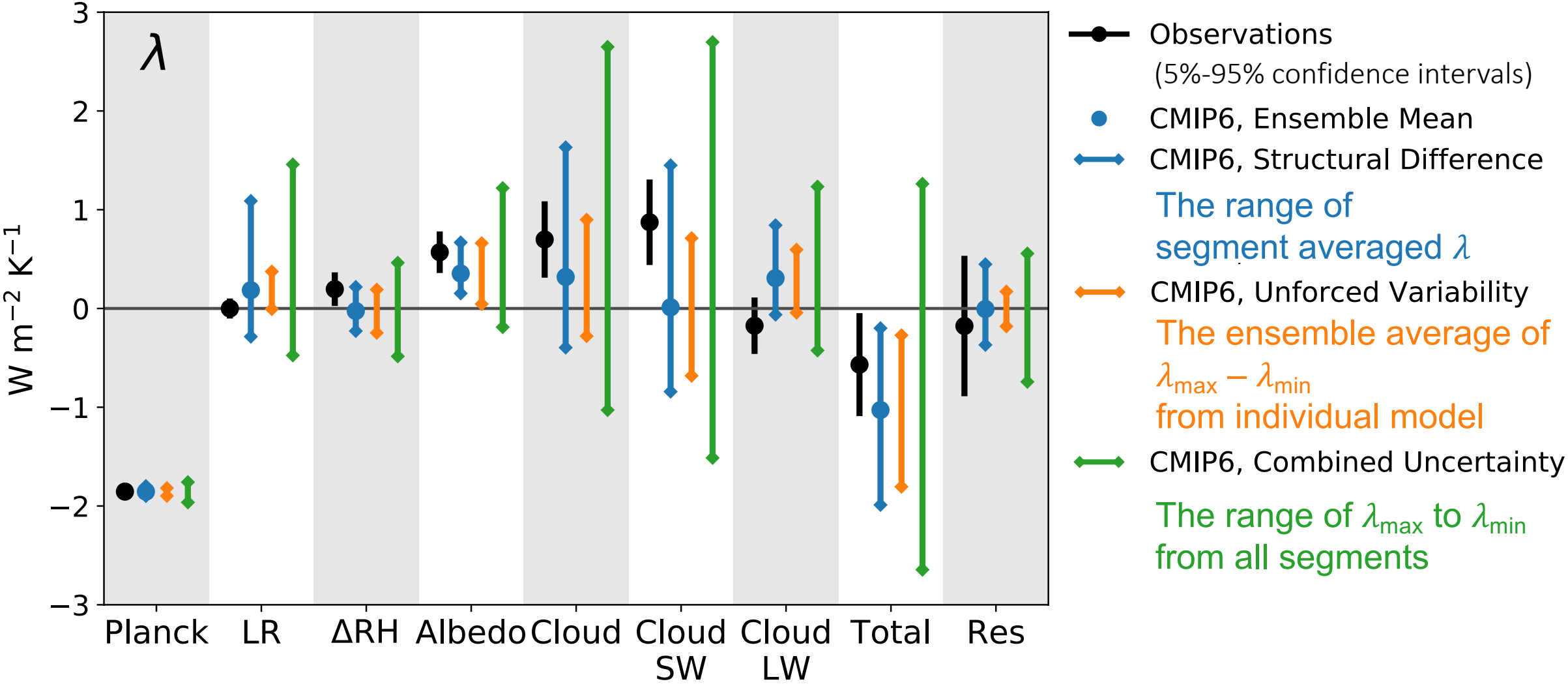
The range of segment averaged λ

CMIP6, Unforced Variability

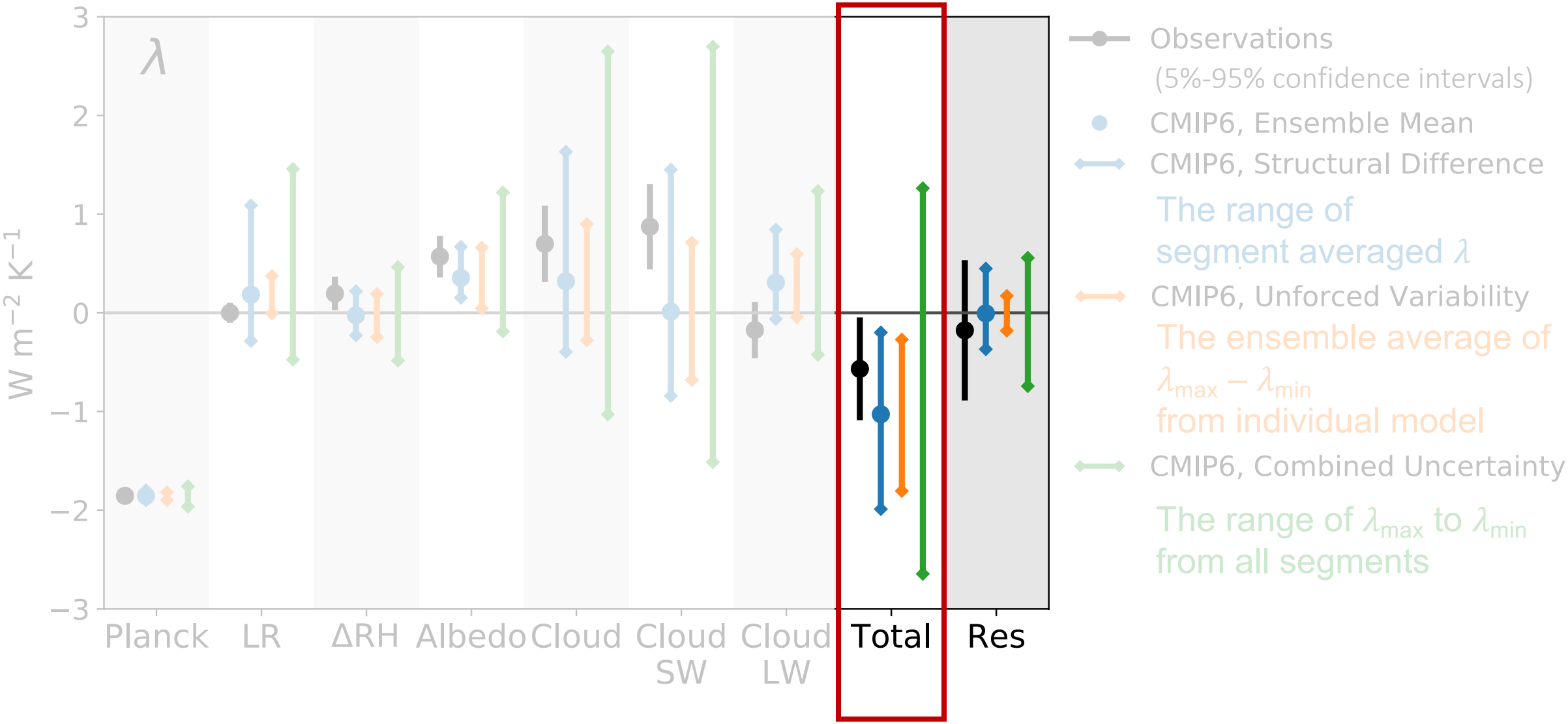
The ensemble average of $\lambda_{max} - \lambda_{min}$ from individual model



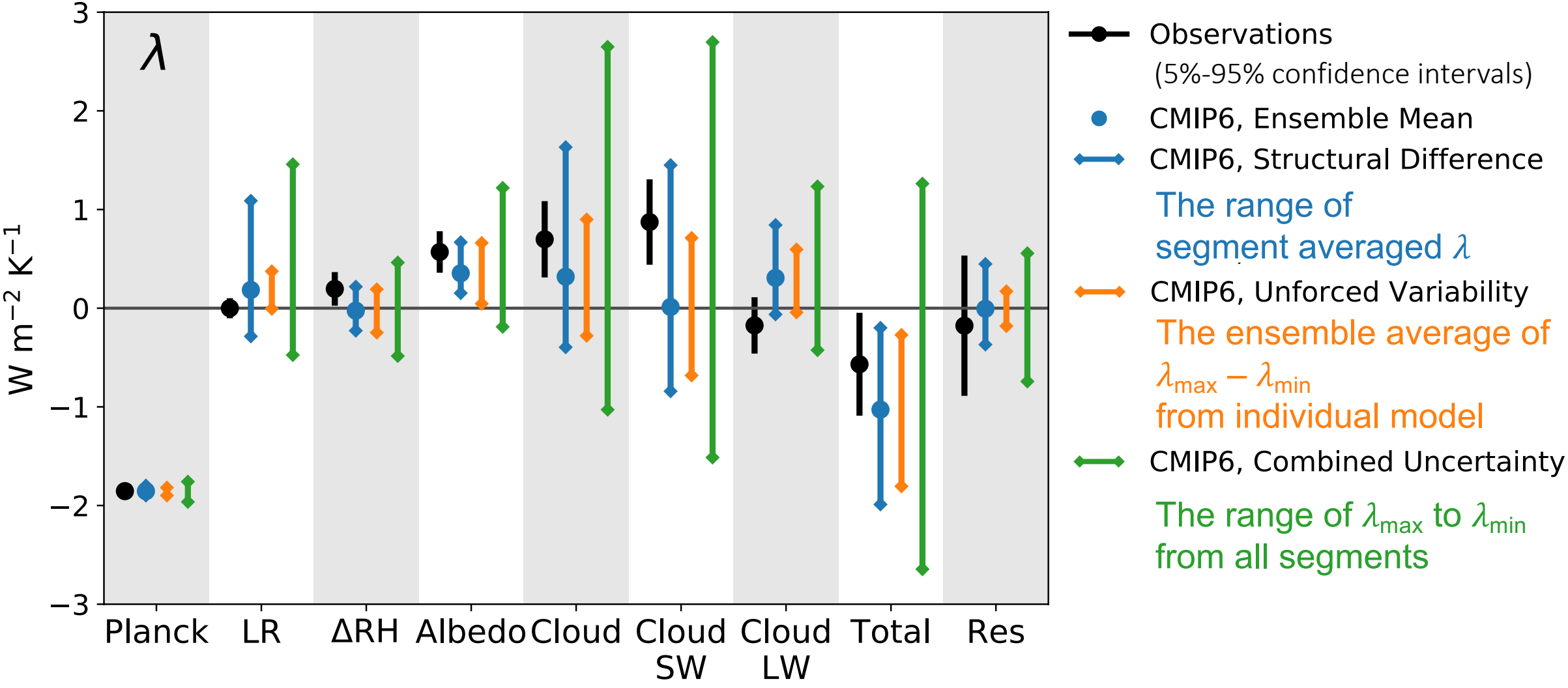
$$\lambda = \lambda_{\text{Planck}} + \lambda_{\text{lapse rate}} + \lambda_{\Delta\text{RH}} + \lambda_{\text{Albedo}} + \lambda_{\text{Cloud}}$$



1. Models could reproduce λ inferred from CERES (λ_{Total}: 52% of segments fall in observation)
2. Climate models have large range
3. The magnitudes of structural difference and unforced variability are comparable in total feedback



1. Models could reproduce λ inferred from CERES (λ_{Total}: 52% of segments fall in observation)
2. Climate models have large range
3. The magnitudes of structural difference and unforced variability are comparable in total feedback

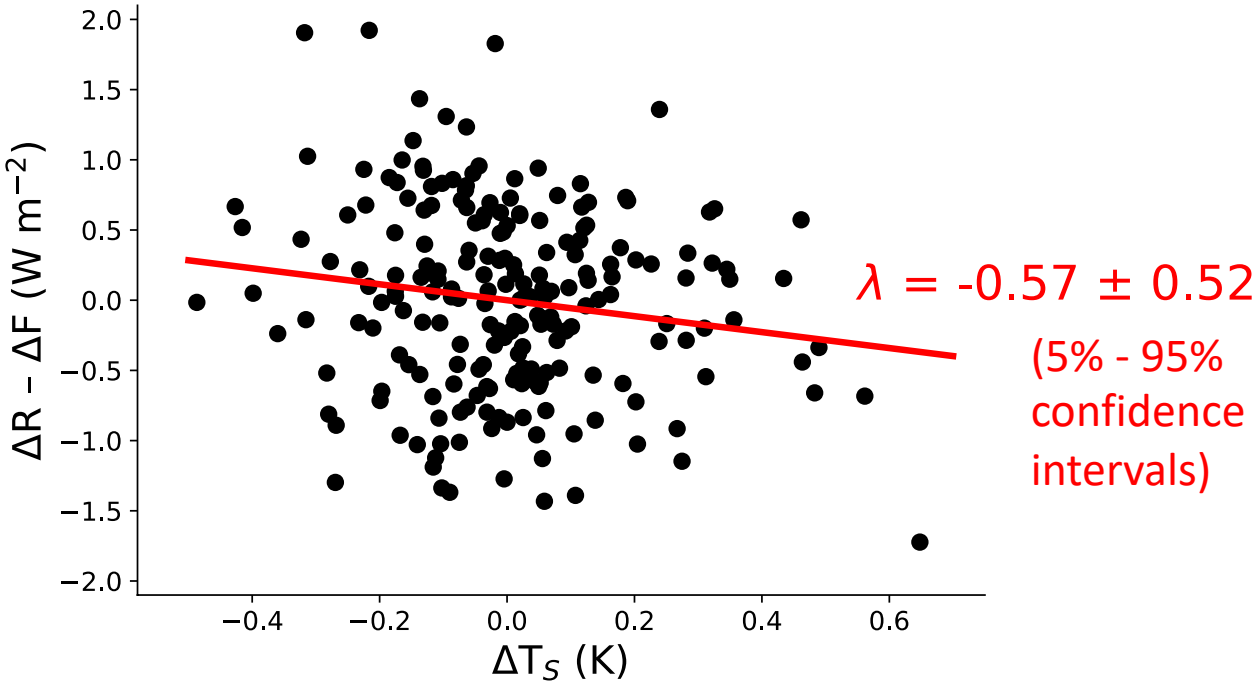


Energy Balance Framework

λ framework:

$$\Delta R = \Delta F + \lambda \Delta T_S$$

- Unforced variability has large influence on the magnitude of λ



Energy Balance Framework

λ framework:

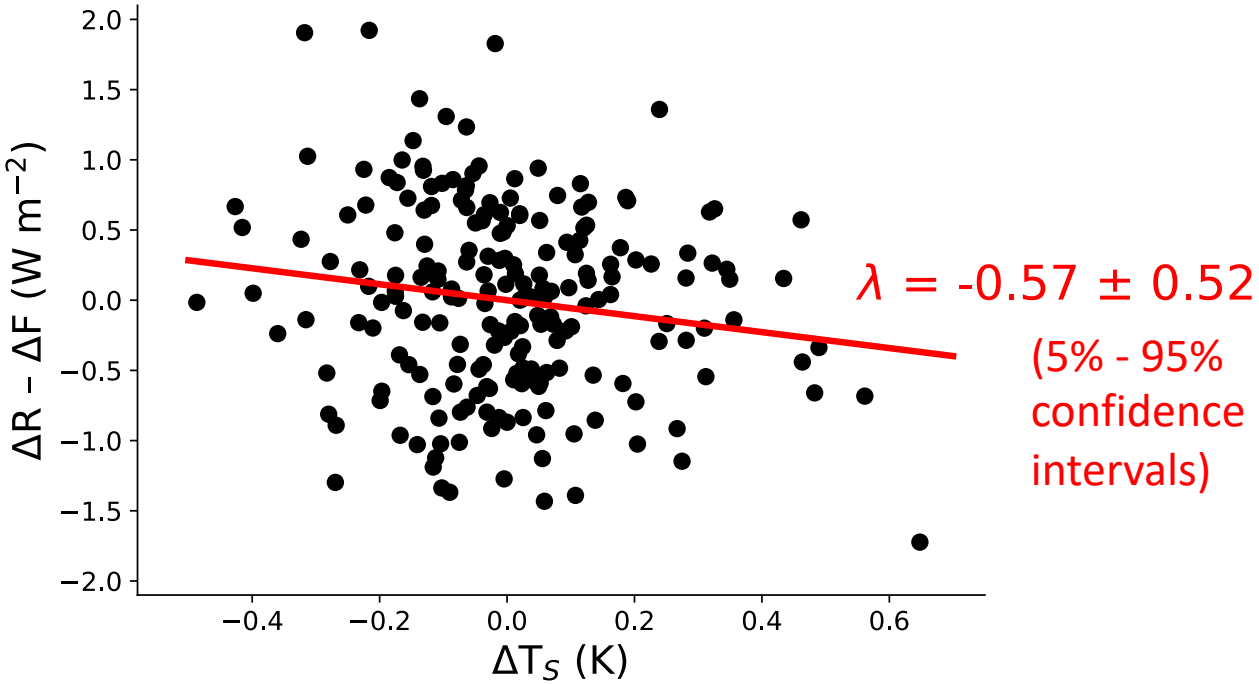
$$\Delta R = \Delta F + \lambda \Delta T_S$$

θ framework: Dessler et al. (2018)

$$\Delta R = \Delta F + \theta \Delta T_{500}$$

Tropical (30˚S-30˚N) 500hPa temperature

- Unforced variability has large influence on the magnitude of λ



Energy Balance Framework

λ framework:

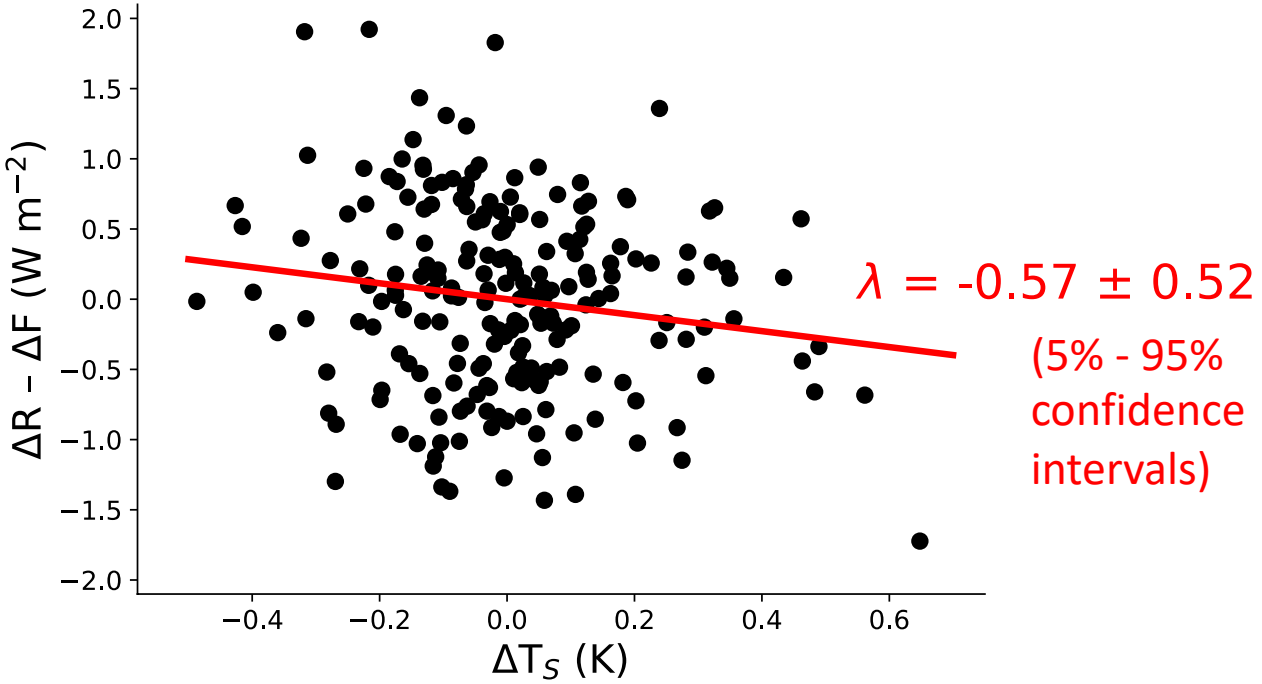
$$\Delta R = \Delta F + \lambda \Delta T_S$$

θ framework: Dessler et al. (2018)

$$\Delta R = \Delta F + \theta \Delta T_{500}$$

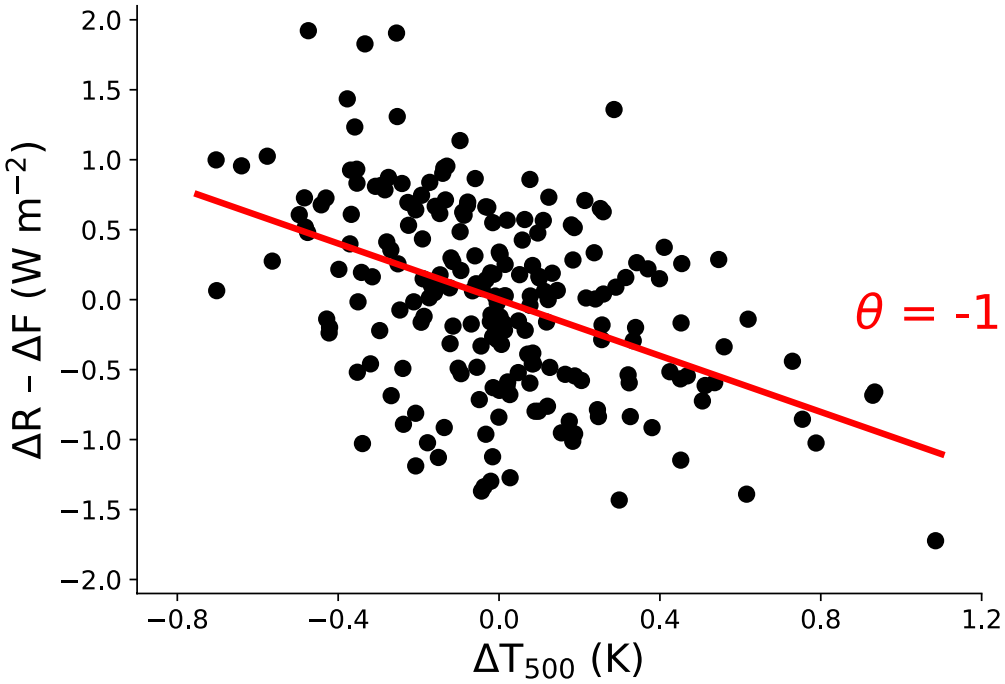
- Unforced variability has large influence on the magnitude of λ

Tropical (30˚S-30˚N)
500hPa temperature



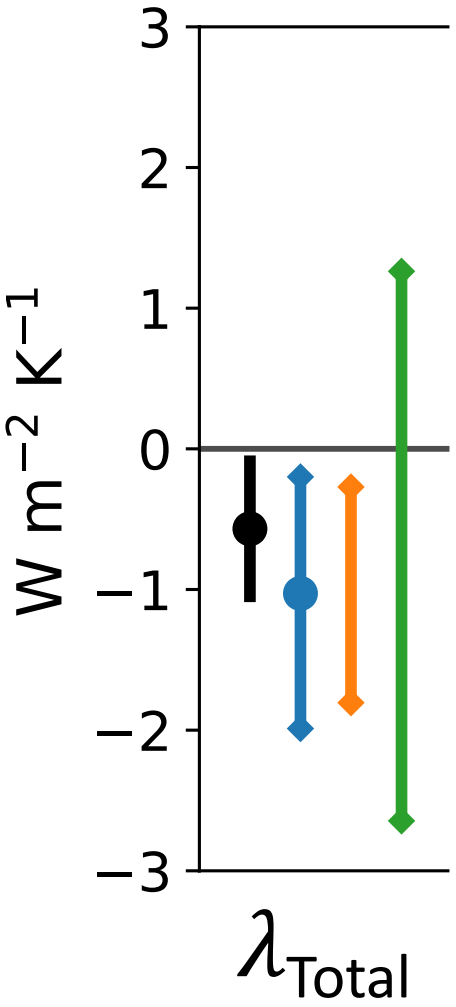
λ = -0.57 ± 0.52

(5% - 95% confidence intervals)



θ = -1.00 ± 0.30

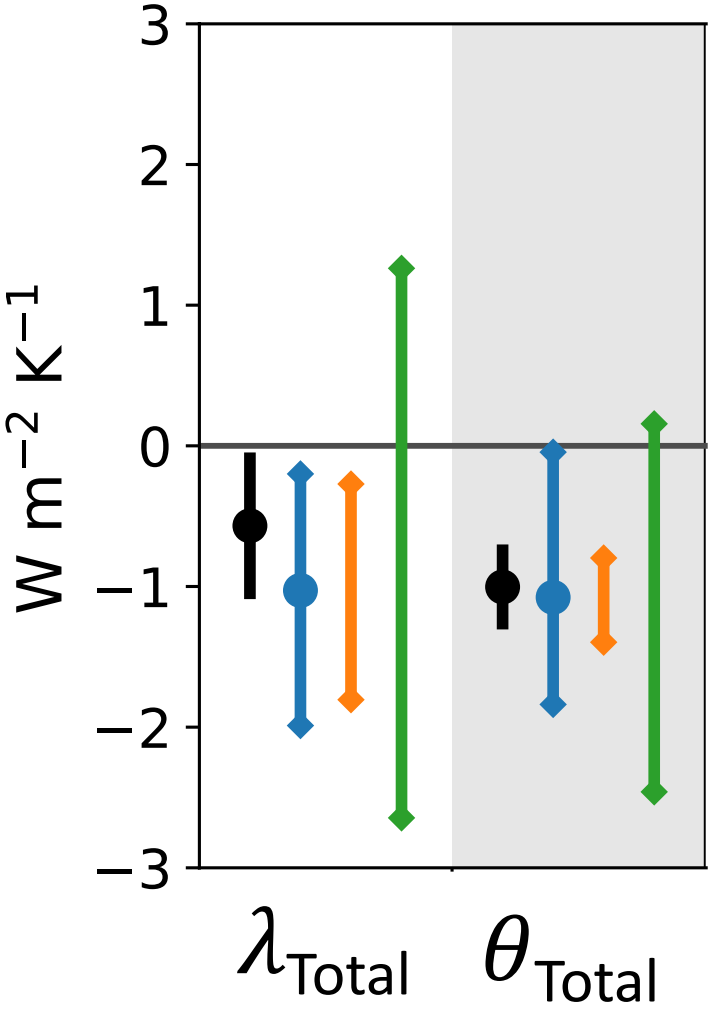
λ framework vs. θ framework



Observations
CMIP6, Ensemble Mean
CMIP6, Structural Difference
CMIP6, Unforced Variability
CMIP6, Combined Uncertainty

λ | θ

λ framework vs. θ framework

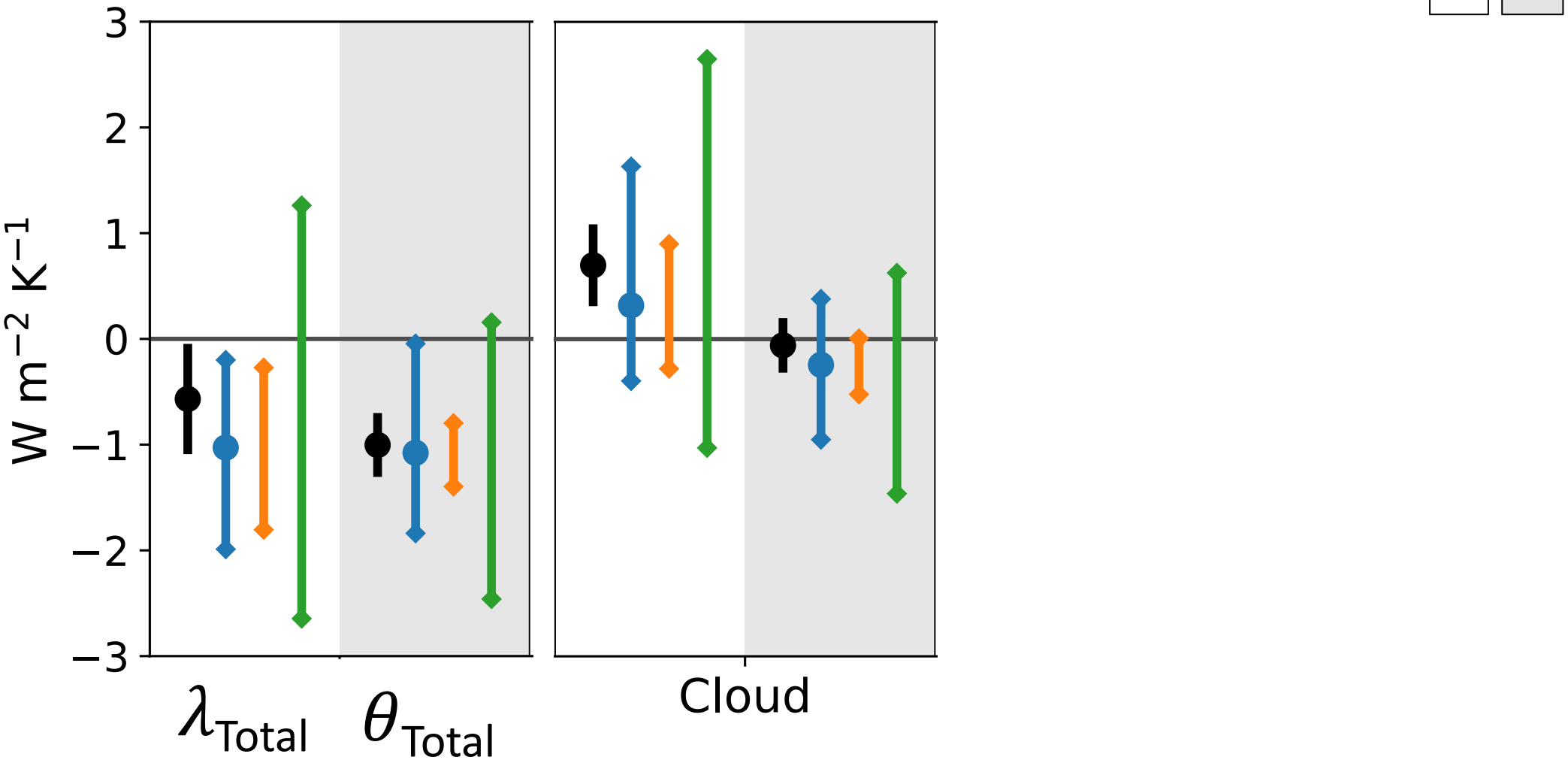


Observations
CMIP6, Ensemble Mean
CMIP6, Structural Difference
CMIP6, Unforced Variability
CMIP6, Combined Uncertainty

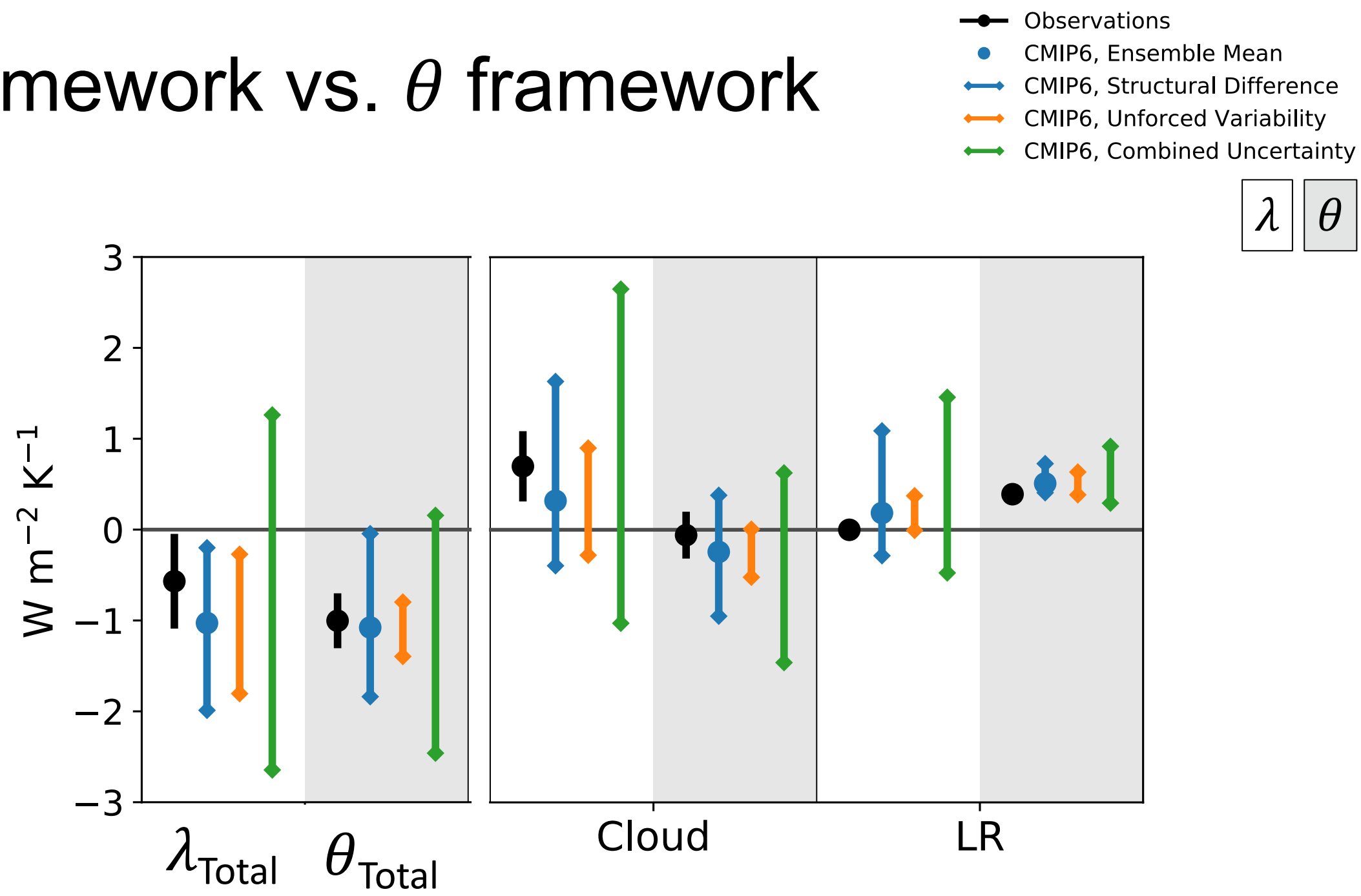
λ | θ

1. CERES observations: the radiative flux is better correlated with 500hPa temperature (θ)
2. The impact of structural difference is similar
3. Unforced variability has less influence in θ

λ framework vs. θ framework



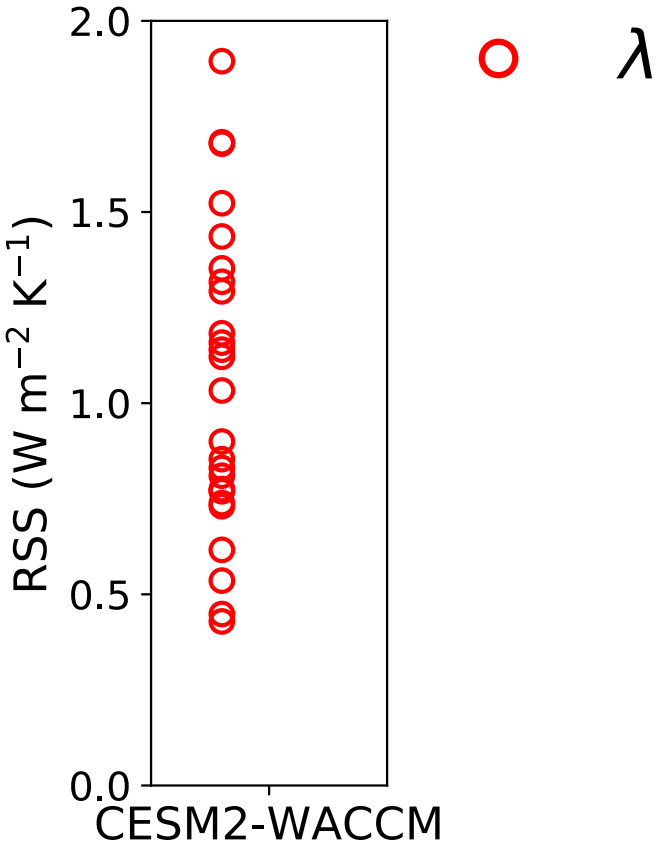
λ framework vs. θ framework



Quantify model performance

$$\mathrm{RSS}_{\lambda} = \sqrt{\sum_i \left(\lambda_{i,obs} - \lambda_{i,model}\right)^2}$$

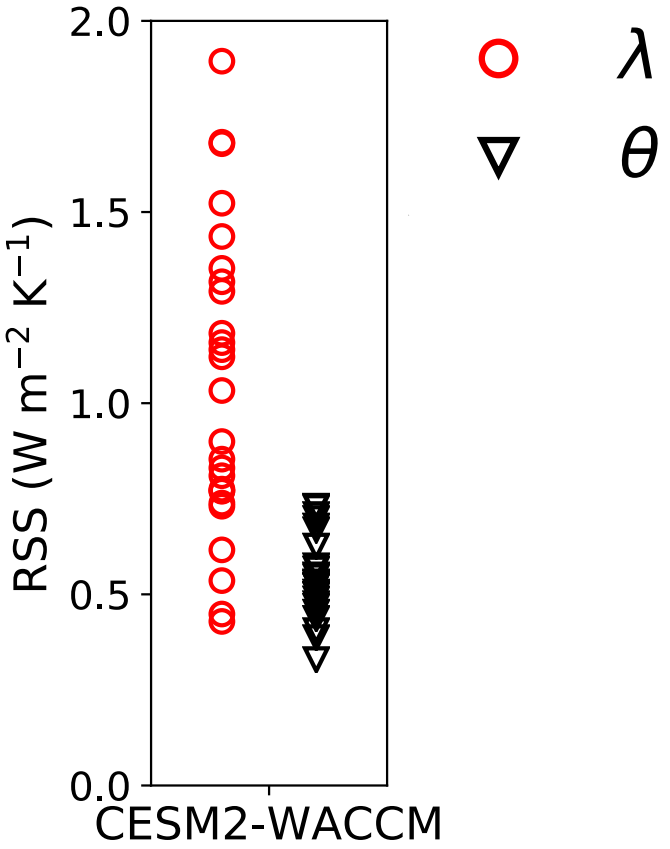
i = Planck, lapse rate, ΔRH, albedo, cloud



Quantify model performance

$$\mathrm{RSS}_{\lambda} = \sqrt{\sum_i \left(\lambda_{i,obs} - \lambda_{i,model}\right)^2}$$

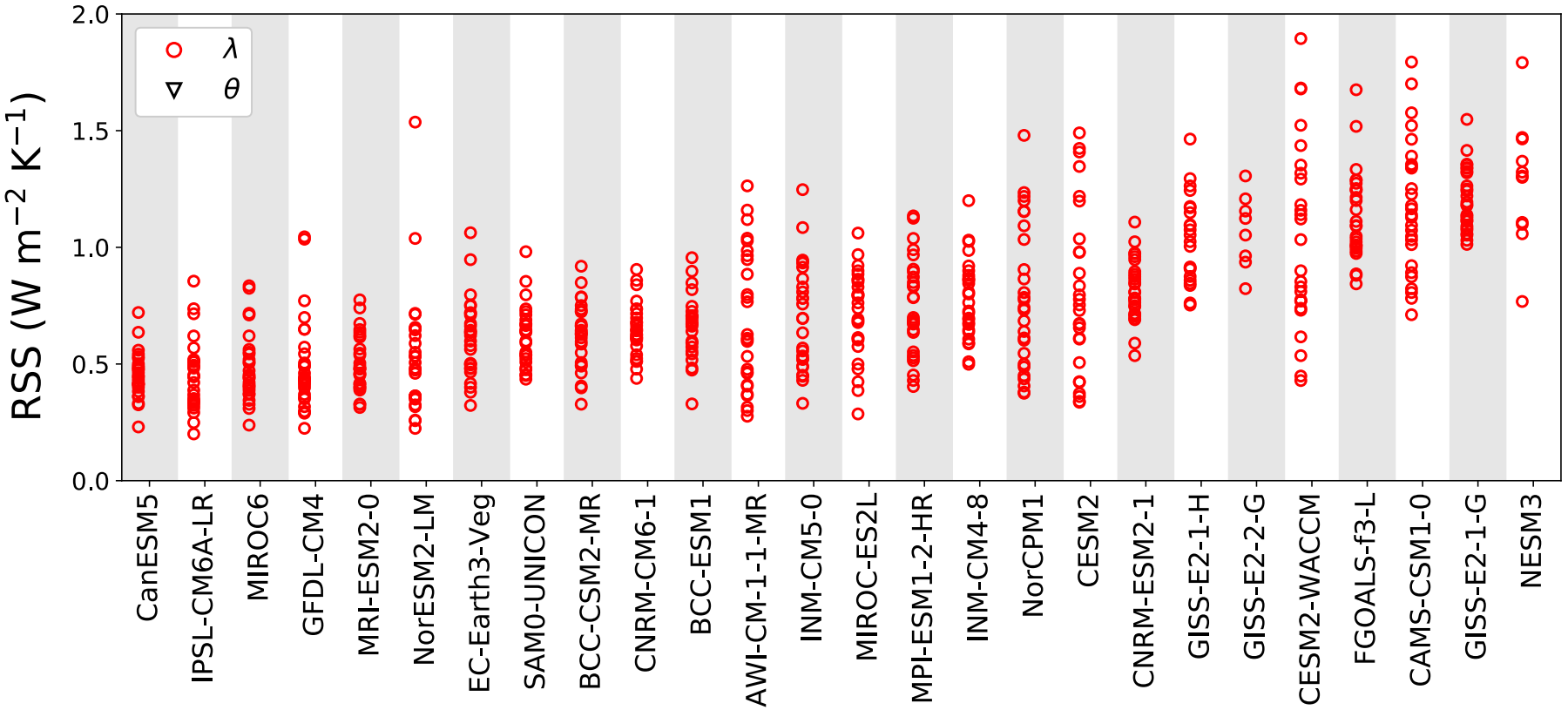
i = Planck, lapse rate, ΔRH, albedo, cloud



Quantify model performance

$$\mathrm{RSS}_\lambda = \sqrt{\sum_i \left(\lambda_{i,obs} - \lambda_{i,model}\right)^2}$$

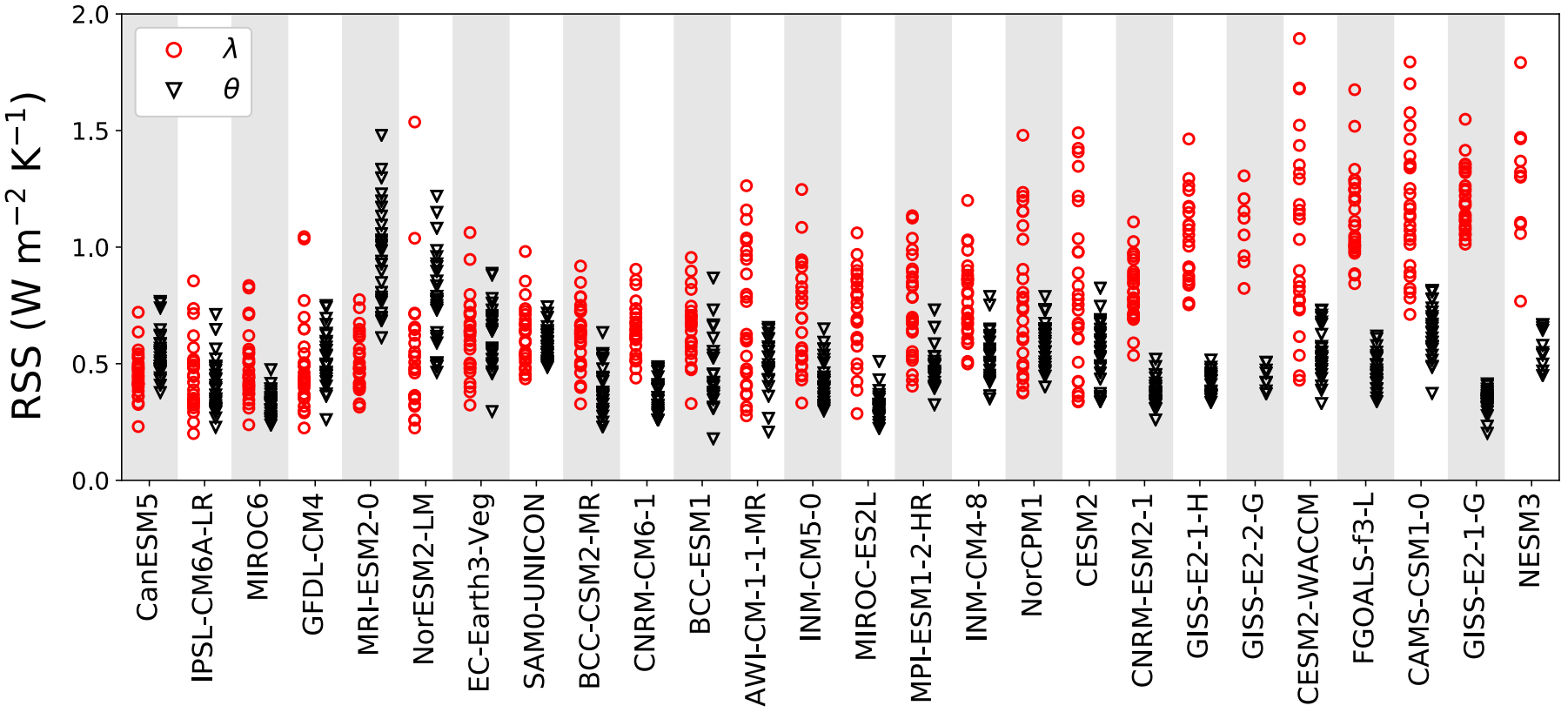
i = Planck, lapse rate, ΔRH, albedo, cloud



Quantify model performance

$$\mathrm{RSS}_\lambda = \sqrt{\sum_i \left(\lambda_{i,obs} - \lambda_{i,model}\right)^2}$$

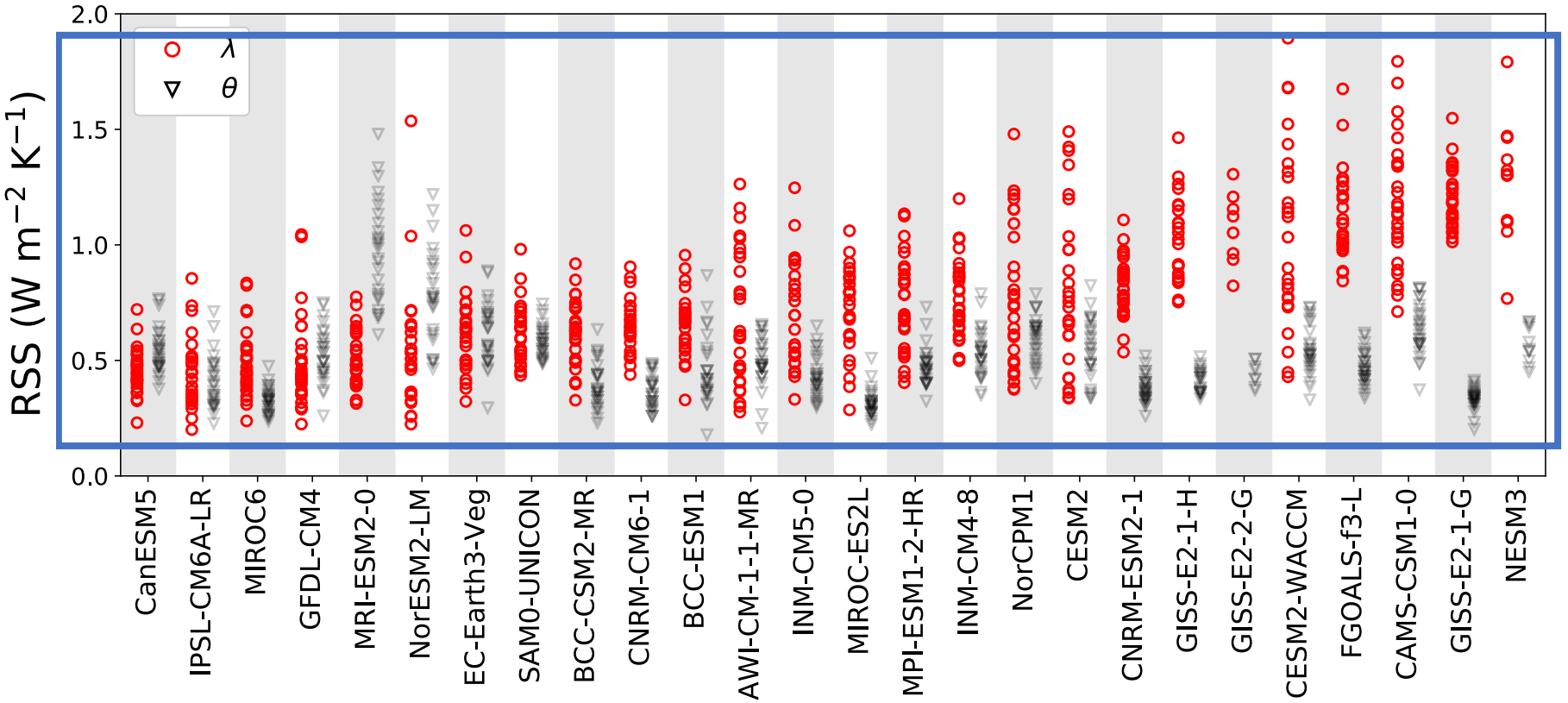
i = Planck, lapse rate, ΔRH, albedo, cloud



Quantify model performance

$$\mathrm{RSS}_\lambda = \sqrt{\sum_i \left(\lambda_{i,obs} - \lambda_{i,model}\right)^2}$$

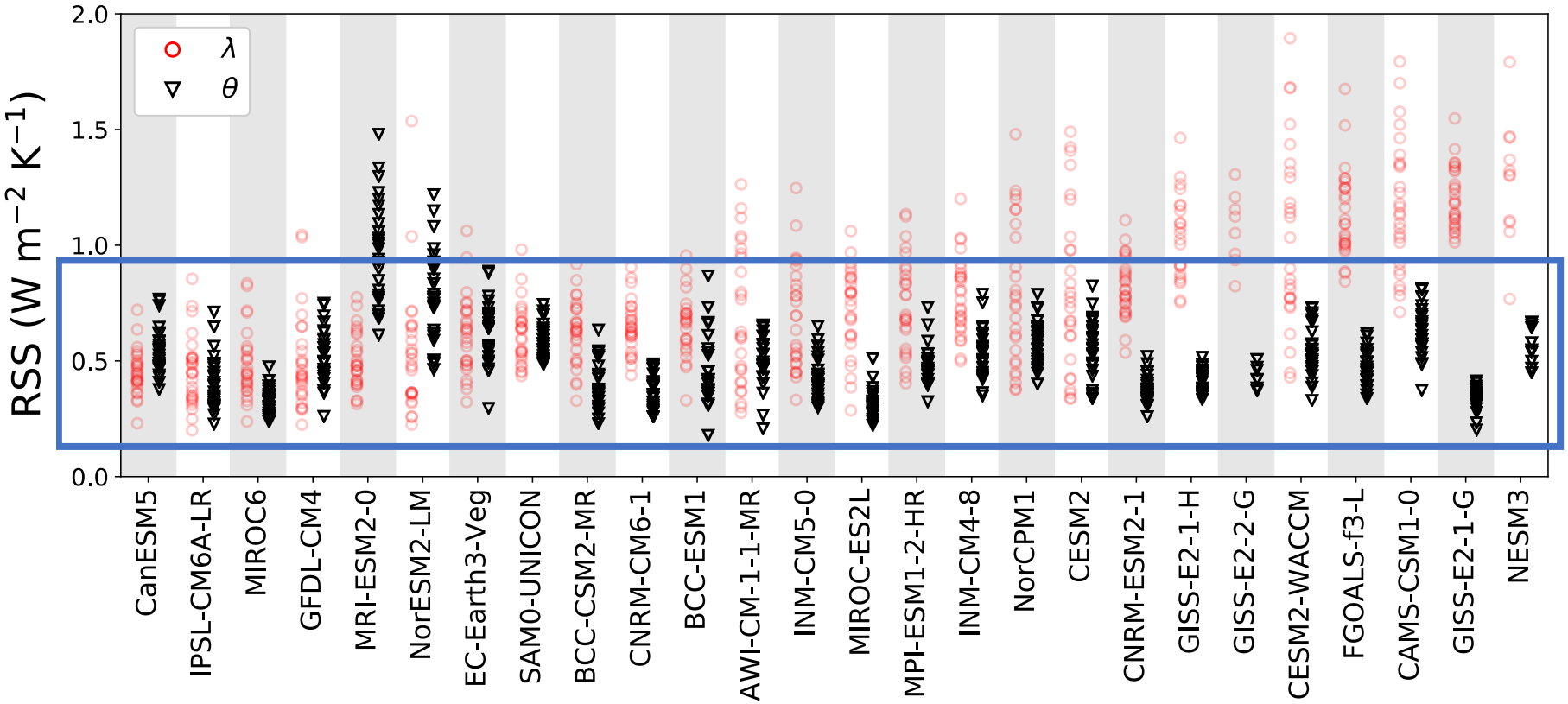
i = Planck, lapse rate, ΔRH, albedo, cloud



Quantify model performance

$$\mathrm{RSS}_{\lambda} = \sqrt{\sum_i \left(\lambda_{i,obs} - \lambda_{i,model}\right)^2}$$

i = Planck, lapse rate, ΔRH, albedo, cloud



Conclusions

- No systematic disagreements between the feedbacks in the model ensembles and feedbacks inferred from observations
- The unforced variability has large influence on the magnitude of feedback
- θ framework yields more robust comparison in model performance:

  (1) Less affected by unforced variability

  (2) Smaller uncertainty in the observations

  → **Better way to test the models**